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A CLASSIFICATION SCHEMA FOR DESIGNING AUGMENTED REALITY EXPERIENCES

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ABSTRACT

Aim/Purpose	Designing augmented reality (AR) experiences for education, health or entertainment involves multidisciplinary teams making design decisions across several areas. The goal of this paper is to present a classification schema that describes the design choices when constructing an AR interactive experience.
Background	Existing extended reality schema often focuses on single dimensions of an AR experience, with limited attention to design choices. These schemata, combined with an analysis of a diverse range of AR applications, form the basis for the schema synthesized in this paper.
Methodology	An extensive literature review and scoring of existing classifications were completed to enable a definition of seven design dimensions. To validate the design dimensions, the literature was mapped to the seven-design choice to represent opportunities when designing AR iterative experiences.
Contribution	The classification scheme of seven dimensions can be applied to communicating design considerations and alternative design scenarios where teams of domain specialists need to collaborate to build AR experiences for a defined purpose.
Findings	The dimensions of nature of reality, location (setting), feedback, objects, concepts explored, participant presence and interactive agency, and style describe features common to most AR experiences. Classification within each dimension facilitates ideation for novel experiences and proximity to neighbours recommends feasible implementation strategies.
Recommendations for Practitioners	To support professionals, this paper presents a comprehensive classification schema and design rationale for AR. When designing an AR experience, the schema serves as a design template and is intended to ensure comprehensive discussion and decision making across the spectrum of design choices.

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Recommendations for Researchers	The classification schema presents a standardized and complete framework for the review of literature and AR applications that other researchers will benefit from to more readily identify relevant related work.
Impact on Society	The potential of AR has not been fully realized. The classification scheme presented in this paper provides opportunities to deliberately design and evaluate novel forms of AR experience.
Future Research	The classification schema can be extended to include explicit support for the design of virtual and extended reality applications.
Keywords	augmented reality, interactive experiences, design rationale, classification schema

INTRODUCTION

Augmented reality experiences typically overlay computer-generated (virtual) content over a technology-mediated depiction of the physical world (R. Azuma et al., 2001). Popular examples include the game Pokemon Go and training modules that generate synthetic information to support the real-world experience. When developing augmented reality (AR) applications, designers create an assortment of imaginative experiences, utilizing a diverse range of technologies (Schmalstieg & Hollerer, 2016), to support opportunities for engagement, immersion, and interaction by the audience (Dey et al., 2018, Milgram et al., 1995). Continued innovation in the design of such experiences becomes increasingly challenging for designers, particularly where only a small portion of the team may be technology experts (Fenu & Pittarello, 2018). AR experiences are utilized for many varied purposes including tourism (Weber, 2016; Xu et al., 2016), education (Harley et al., 2016; Radu, 2012; Richardson, 2016; Schneider et al., 2017), and exhibitions (Tsai et al., 2017). Challenges include ensuring consensus and common vocabulary within cross-disciplinary teams; achieving consistency and completeness in an AR experience design specification; and considering the range of opportunities available with AR technologies. In our experience, virtual reality (VR) and augmented reality have been used to variously refer to systems involving the use of a head-mounted display, 360-degree video, desktop 3D graphics, or 3D graphics on a mobile device or web browser. Such differences in the most fundamental concepts complicate the design process, despite being technically correct. Other taxonomies (Normand et al., 2012) focus on technical (or techniques) classification, integration with the user, representation of information, or interaction strategy. We identify a gap concerning navigating the design space of applied AR applications.

The goal of this paper is to comprehensively define the design opportunities for AR experiences by developing a classification schema that systematically describes design choices. To achieve the goal, this paper generates a classification schema specifically focused on supporting the design of AR experiences. This classification schema is derived from reviewing existing literature taxonomies related to extended reality, interactive applications, and experience design (second section). The schema is then validated through mapping of the literature review case studies to the schema (fourth section).

LITERATURE REVIEW: CLASSIFYING REALITIES

The well-known Milgram scale (Milgram et al., 1995) defines a linear continuum of real-to-virtual environments in which AR is one part of the general area of mixed reality. This can be extended to consider the broader application of mixed reality to technologies used, content, and user experience (Skarbez et al., 2021). Mixed reality defines a wide range of applications that situate digital information in the world (Rouse et al., 2015) by the simultaneous perception of real and virtual (Normand et al., 2012; Skarbez et al., 2021). The real-to-virtual continuum classifies applications that aim to alter the user's sense of reality. On one end, virtual environments completely immerse the participant in a synthetic environment (R. T. Azuma, 1997), whereas AR, defined towards the 'real' end of the continuum, is where the virtual content is overlaid over the participant's perception of the world (Nilsen et al., 2004), but with a tight coupling of graphics to the visual surrounds (Rouse et al., 2015). Diminished reality (R. Azuma et al., 2001) is a subset of AR, a reality that removes objects, asking the participant to rely on their senses to mediate the experience. Multimediated reality (Mann et al., 2018) extends the previous classification across disciplines, forms of media, and sensory experiences. Further to AR and VR, pervasive reality (PR) is that which transcends place and time and can be played in many diverse places and for extended periods (Avouris & Yiannoutsou, 2012; Diaconu et al., 2018), exploiting contextual information within the environment (Chatzidimitris et al., 2016; Silva et al., 2016), or making use of situated media (Guven, 2006). Ubiquitous reality, a subset of pervasive reality, embeds computing technology in the natural environment to support interaction with physical elements (Cheok et al., 2002). Alternate reality, on the other hand, provides a mixed reality experience that adds new narratives to the real-world setting (Deterding et al., 2011; Silva et al., 2016). The precise boundaries of these alternative realities rightly remain vague (Ch'ng et al., 2017). While we use AR as the primary term throughout this paper as it is often incarnated in highly varied forms, the classification schema is also able to provide greater resolving power in describing the diversity of mixed reality experiences.

AR is more than the registration of objects onto locations in the physical setting and demands consideration of the nature of the interactive experience (Aluri, 2017; R. Azuma et al., 2001; Collins et al., 2017; Skarbez et al., 2021; Steuer, 1992). In addition, interactive agency and style should also consider the social interaction (Dunleavy et al., 2009; Joo-Nagata et al., 2017; Papathanasiou-Zuhrt et al., 2017), context (R. T. Azuma, 1997; Barfield & Rosenberg, 1995; Ganapathy, 2013), and presence (Hansen, 2012; Milgram et al., 1995; Silva et al., 2016; Slater & Wilbur, 1997).

Existing AR case studies and frameworks are often described using technology-mediated classifications (Avouris & Yiannoutsou, 2012; R. T. Azuma, 1997; Diaconu et al., 2018; Endsley et al., 2017; Fedorov et al., 2016; Pryss et al., 2016; Skarbez et al., 2021; Speiginer & Maclntyre, 2018), with reference to hardware and software options and affordances. Indoor and outdoor AR experiences are distinguished because of the impact they have on the tracking and registration of content (Avouris & Yiannoutsou, 2012; R. T. Azuma, 1997; Freschi et al., 2015; Hansen, 2012). Display devices are classified using categories such as handheld, head-mounted display (semi-transparent and camera), projective and multi-modal displays (R. Azuma et al., 2001; Barfield & Rosenberg, 1995; Cheng et al., 2019; Skarbez et al., 2021), while interaction devices and metaphors are more diverse (R. Azuma et al., 2001; Ganapathy, 2013). Several classes of devices (such as backpack systems) and issues (monochrome line graphics) (Barfield & Rosenberg, 1995; Milgram et al., 1995) have been superseded by hardware advances. The classification schema proposed in this paper purposefully focuses on design choices over technology considerations. While technology is integral to an AR experience, an experience design needs to consider many additional factors and these can be explored before introducing constraints relating to the application in practice.

Ideally, the design of augmented reality applications should include the multiple aspects of the experience (Endsley et al., 2017), incorporating a range of specialist design and development skills (Fenu & Pittarello, 2018), and an understanding of the needs of the participants (Brederode et al., 2005; J. J. Lee et al., 2013) and context (Ganapathy, 2013). Imaginative AR experiences extend participant presence throughout the location, across time, and between participants (Carlson et al., 2018; Castaneda et al., 2018; Fernandez-Vara, 2009; Harley et al., 2016; Oleksy & Wnuk, 2017) and operate at levels of abstraction from conceptual knowledge to mechanical skills (de Ribaupierre et al., 2014; Deterding et al., 2011; Harley et al., 2016; Nilsen et al., 2004; Roo & Hachet, 2017).

Relevant design frameworks (Deterding et al., 2011; Lundgren & Bjork, 2003; Milgram et al., 1995) focus on different aspects of the experience, including augmented reality, live-action virtual reality (Silva et al., 2016), ubiquitous computing, games (Walk et al., 2017), exergames (Fernandez-Cervantes et al., 2016; Planinc et al., 2013), location-based games (Weber, 2016), persistent and alternative reality experiences, performance (Fernandez-Vara, 2009), embodiment (Lindgren & Moshell, 2011), and education (Kamarainen et al., 2013).

REVIEW METHODOLOGY

Google Scholar was used to identify the diverse range of existing literature relevant to the design of AR experiences. Keywords such as 'Augmented Reality', 'Augmented Experiences', 'Design,' and 'Mixed Reality' were used to query relevant works, with scholarly sources and AR application case studies includes as outcomes. Google Scholar was also used as an index for open access and other journal sources, with all papers cited taken from peer-reviewed sources. This approach ensured that the literature represented a multidisciplinary view of augmented and extended reality. As in comparable investigations (Avouris & Yiannoutsou, 2012), this review selects papers from the identified set that inform the classification schema by either presenting relevant design classification schema themselves, or by describing AR relevant case studies suitable for categorization using the design classification schema. Papers are eliminated where the focus is on the workings of a particular technology element or interaction mechanic, focusing instead on relevance to AR experience design. This is a point of distinction relative to previous literature reviews of this nature (Avouris & Yiannoutsou, 2012; R. Azuma et al., 2001; Diaconu et al., 2018; Endsley et al., 2017; Fedorov et al., 2016; Pryss et al., 2016). Table 1 summarizes review outcomes. The review grouped the literature into common themes (or dimensions) (Mann et al., 2018; Speicher et al., 2019). Over 90 sources were identified to be included in the literature review for this study. Initially, papers were grouped by the paper's authors based on the subject matter, with existing AR literature forming 26 groups. These groups were then further refined to form seven categories that describe the existing AR experience literature. The existing groups and the final category description are shown in Table 1. Each reference relevant to the initial grouping (26) is shown in the left-hand side column.

Table 1. Mapping of existing AR classification criteria to the schema presented in this paper

Existing AR experience classification criteria	Category descriptor used in this paper
Nature of experience/reality (defined as natural, virtual, mediated, alternating, mental, emotional, or imaginative) (Hoang & Cox, 2018; Nilsen et al., 2004; Speicher et al., 2019; Stapleton et al., 2002; Steuer, 1992). *Form of Augmentation* (participant or environment) (Hansen, 2012; Silva et al., 2016), extent of augmentation (user, world) (Normand et al., 2012), sensory experience (Skarbez et al., 2021), technological environment layer (Speiginer & Maclntyre, 2018). *Digital twins continuum* (twins, digital natives, co-existing realities) (L.-H. Lee et al., 2021), Society 5.0 (Suzuki et al., 2020). *Connection* (absorbing content versus immersed in an experience) (Aluri, 2017; de Ribaupierre et al., 2014; Rouse et al., 2015; Stapleton et al., 2002).	Nature of Reality
Dependency on a particular place/location (Rouse et al., 2015; Silva et al., 2016). *Environment* (with categories of real local, real remote, and synthetic) (Collins et al., 2017; Slater & Wilbur, 1997; Steuer, 1992), spatial environment layer (Speiginer & Maclntyre, 2018). *Focus* (on impact of experience, location or other people) (Dunleavy et al., 2009; JooNagata et al., 2017; Papathanasiou-Zuhrt et al., 2017). *Form of Augmentation* (see Nature of Reality)	Location (setting)

Existing AR experience classification criteria	Category descriptor used in this paper
Interactivity (Aluri, 2017; R. T. Azuma, 1997; Collins et al., 2017; Steuer, 1992; Speicher et al., 2019). *Modality* (video, audio, haptic, taste, smell) (Barfield & Rosenberg, 1995; Normand et al., 2012; Speicher et al., 2019). *Feedback cues* (L.-H. Lee et al., 2021). *Lighting* (Collins et al., 2017; Dey et al., 2018). *Coherence* (internal, external) (Skarbez et al., 2021).	Feedback
Objects (R. T. Azuma, 1997; Collins et al., 2017; Fernandez-Vara, 2009), augmentation layer (Speiginer & Maclntyre, 2018). *Modality* (see Feedback, row 3).	Objects
Experience context (medical, collaboration, manufacturing, training, architecture, visualization, entertainment, commerce, tourism) (R. T. Azuma, 1997; Barfield & Rosenberg, 1995; Ganapathy, 2013). *Educational experiences* (Avouris & Yiannoutsou, 2012; de Ribaupierre et al., 2014; Joo-Nagata et al., 2017; Radu, 2012).	Concepts Explored
Immersion and presence (Milgram et al., 1995; Skarbez et al., 2021; Slater & Wilbur, 1997; Speicher et al., 2019). *Collaboration* (R. T. Azuma, 1997; Dey et al., 2018; Dunleavy et al., 2009; Nilsen et al., 2004; Slater & Wilbur, 1997; Speicher et al., 2019). *Target audience* considerations (Fenu & Pittarello, 2018). Utilisation of *social connections* (Clark & Clark, 2016; Papathanasiou-Zuhrt et al., 2017). *Focus* (see Location).	Participant Presence
Game play elements (Avouris & Yiannoutsou, 2012; Fernandez-Vara, 2009; Harris, 2018; J. J. Lee et al., 2013; Weber, 2016). Participant *plays a role* as an actor (Carlson et al., 2018; Schneider et al., 2017; Steuer, 1992). Contains a *story line* (Avouris & Yiannoutsou, 2012; Schneider et al., 2017; Slater & Wilbur, 1997). *Focus* (see Location).	Interactive Agency and Style

CLASSIFYING DESIGN CHOICES FOR AR

When classifying design choices for AR, our synthesis classifies over 90 papers by grouping these into seven dimensions, demonstrating explicit considerations. The seven dimensions include the nature of the reality presented, the way the location is portrayed, the form of feedback provided to participants, the way in which objects mediate interaction, the nature of the concepts assimilated, the ways in which participants engage with the experience and one another, and how the experience incorporates the user. In each dimension, further classification occurred resulting in a triangle to represent the spectrum on which the dimension mediated elements of the AR experience (Mann et al., 2018). These produced coordinates quantified relative to 3 axes defined by these labels, similar to those in Normand et al. (2012). Using three axes to define each dimension aligns with Dervin's approach to sense-making (Hajdu Barat, 2010) which defines three types of information: information that is incomplete-objective and includes external reality; information that is subjective and includes internal reality; and information that includes the way in which a person becomes informed.

For five of the design dimensions presented in this paper, the literature is grouped into three axes per triangle: physical, virtual, and abstract. For the other two dimensions, the literature grouped similarly generated three axes relative to the design choices available in the literature. Figures 1 to 7 demonstrate each design dimension and how the literature mapped to the dimensions by axis. In each dimension, these axes support the spread of literature relevant to each dimension, demonstrating the degree to which the synthetic world is represented in the AR experience and offering explicit choices for designing to engage in a process of sense-making (Hajdu Barat, 2010) when putting together the components of an AR experience. Further detail regarding what each axis means in relation to each dimension is presented in the next section.

Each of the original criteria grades an AR experience either on a spectrum between two extrema or as one category in a fixed set of options (Mann et al., 2018). Our proposal aims to capture both these aspects by employing a polygon representation with labelled vertices. Any AR application is then categorized by marking a point within the interior of the polygon, with proximity to each vertex representing the degree to which the experience achieves the corresponding label.

Each paper reviewed that overlaps with one or more dimensions is assigned barycentric coordinates for those dimensions, which are 3D coordinates that sum to 1 where the paper describes a design that meets a particular classification, with a lower total score (0.5 or below) where the relationship is less explicit. Coordinates were assigned by the two authors each working independently on half the papers. The scores were then compared and normalized during a joint meeting. The classification outcome for each dimension is described and plotted in the sections that follow, along with a detailed description of each dimension's coordinates in relation to the relevant literature. Minor zero-mean random perturbations in the coordinates plotted are used in these diagrams to support the visualization of clusters. Abbreviated citation keys are used to aid readability.

NATURE OF REALITY

The nature of reality dimension classifies the complete experience and extends on the Milgram scale (Milgram et al., 1995) with its categories of physical and virtual reality, by including an orthogonal category of abstract reality that extends the computer-mediated experience with human-mediated elements. Any form of mediated communication can provide an experience that transports the audience (Steuer, 1992), from placing the reader in a story-like novel through to acting upon a narrative in a video game. A consideration when designing an AR experience should be what the desired experience should provide in terms of the representation of reality (Chen et al., 2013). The literature exploring existing AR experiences shows a mix between virtual and physical realities (R. T. Azuma, 1997; Collins et al., 2017; Lindgren & Moshell, 2011; Lukyanenko, 2016; Nilsen et al., 2004; Rouse et al., 2015). Providing an AR experience, as with MR, relies on the perceptually successful blending of reality and virtuality, providing a coherent set of stimuli for the participant (Collins et al., 2017), or an interweaving of experience that alternates between the real and virtual environments (Hoang & Cox, 2018).

When defining the nature of reality, we define three vertex labels: ***physical*** as that which relates to the way in which the real world is experienced through the participant's senses; ***virtual*** which is provided through a computer-mediated experience not detectable through a participant's own unaugmented senses, and ***abstract*** experiences may be a combination of physical and virtual components, but rely on imagination, willing disbelief, and human mediation to consider the representation of reality provided (Aluri, 2017; Stapleton et al., 2002). A blend of the factors – abstract, physical, and virtual – is required to define the nature of reality presented in any AR application, as shown in Figure 1.

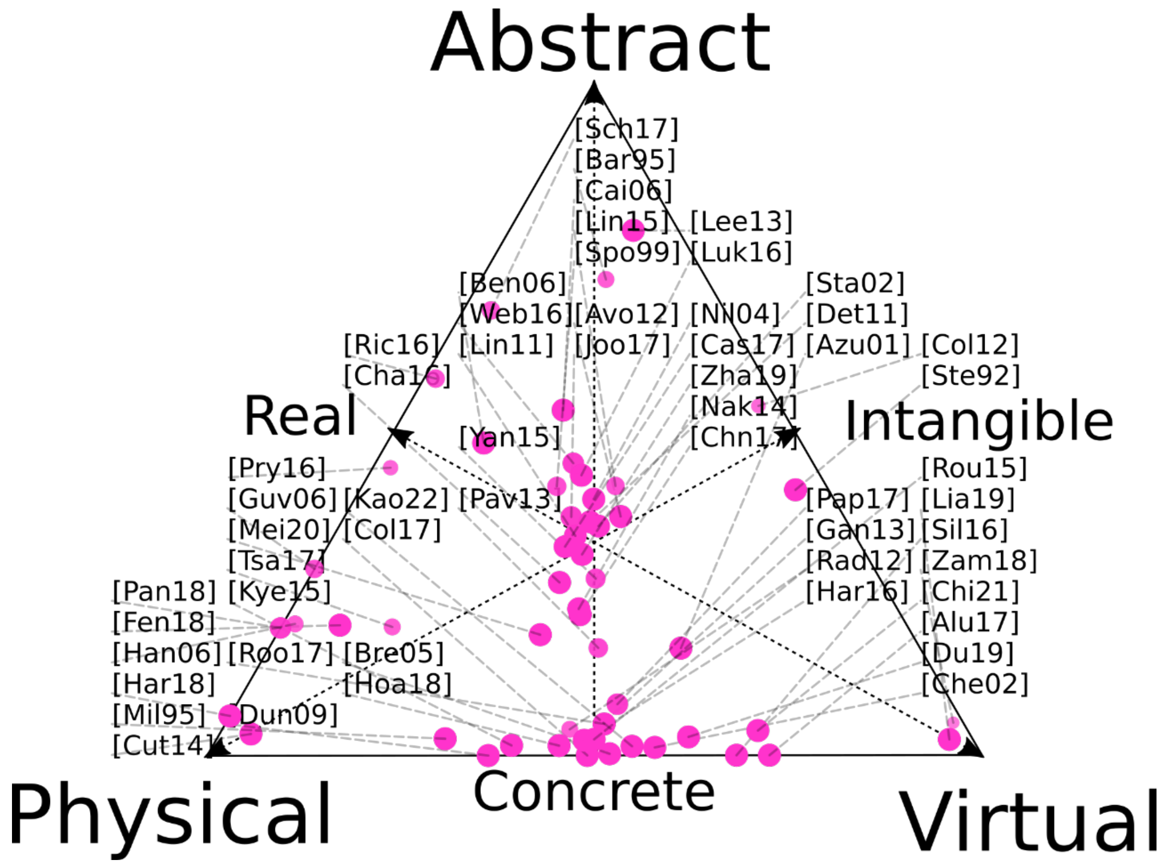

Figure 1. Defining nature of reality

A purely ***physical*** reality corresponds to traditional reality within the physical world and uses elements consistent with that environment. ***Virtual*** refers to a computer-generated representation that is physically plausible but represents a world that is not present at that location at that time. ***Abstract*** refers to concepts that have non-traditional representations that may require human-mediated suspension of disbelief or invoke an imaginative process such as when reading a book. Of the minor (edge midpoint) categories, ***real*** (converse of virtual) refers to physically based elements or concepts available in the world, rather than purely virtual. ***Concrete*** (converse of abstract) defines the level of imagination required by the participant during the interactive experience. ***Intangible*** (converse of physical) reality is not physically available but can be suggested through some form of augmentation. The goals of the experience will direct the concepts included, informing expectations on participant outcomes.

A participant's connection to the nature of the reality relates to their feeling of embodiment (Stapleton et al., 2002) and whether the physical structure of the human body dictates the nature of the experience or needs to adapt to the digital environment by sensing and perceiving abstractions (Hansen, 2012; Radu, 2012).

This mix of physical and virtual can be perceived in different ways by participants, allowing potentially imaginative, abstract and participant rendered representations of reality (Avouris & Yiannoutsou, 2012; R. T. Azuma, 1997; Brederode et al., 2005; Cheok et al., 2002; Ch'ng et al., 2017; Collins et al., 2017; Dunleavy et al., 2009; Harley et al., 2016; Hoang & Cox, 2018; Kysela & Storkova, 2015; Nakevska et al., 2014; Roo & Hachet, 2017; Rouse et al., 2015).

Experiences that rely heavily on capturing content from the physical world, such as visiting historical landmarks (Harley et al., 2016; Pavlik & Bridges, 2013), a museum (Fenu & Pittarello, 2018; Papathanasiou-Zuhrt et al., 2017), or playing Pokémon Go (Aluri, 2017), are representing a physical reality. Technology-enhanced street theatre, where the audience interacts with both the unaltered environment as well as props and performers as part of the unfolding drama (Benford et al., 2006), provides a physical human-mediated connection for this audience within a technology influenced environment. In a pervasive reality, city lighting can sense participants and actively guide them in the physical world to achieve their goals (Diaconu et al., 2018). Often, human actors provide a physical augmentation (Papathanasiou-Zuhrt et al., 2017) by playing a role in an unfolding narrative, or providing information relevant to the history of the location (Joo-Nagata et al., 2017), although their roles may represent virtual or abstract content.

Experiences that rely on presenting a computer-generated reality, such as showing a landmark as it used to appear (Avouris & Yiannoutsou, 2012), interacting with a virtual guide (Harley et al., 2016), exploring a situated documentary or narrative (Dunleavy et al., 2009; Lin & Chen, 2015; Pavlik & Bridges, 2013), or playing AR Quake (R. T. Azuma, 1997), are representing a virtual reality. Digital artworks promote cultural awareness (Papathanasiou-Zuhrt et al., 2017), complementing the existing tourist attractions with virtual content that can be accessed at the participant's discretion. The synthetic component of an augmented-reality presentation does not need to be highly realistic imagery to convey meaning (Barfield et al., 1995), and can even provide a deliberate ambiguity between the fictional and the real world (Benford et al., 2006).

Augmented reality experiences can increase the demand on the participant's attention (Weber, 2016) leading to disengagement from the physical space and a move towards imaginative abstract settings that embrace the magic circle such as a fictional role that represents an alternative image of self (Yan et al., 2015). Games provide a structure to create fictions separated from real life, such as a tabletop game projected on a horizontal surface (Brederode et al., 2005). The make-believe abstract reality adjacent to the physical (Brederode et al., 2005; Caillois, 2006; Chatzidimitris et al., 2016) provides the opportunity to explore a space that cannot be provided to scale in the real world (Cole et al., 2012; Dunleavy et al., 2009). Abstract representations remove the participant from "realistic" reality and present concepts including past, future, or imaginative fictional settings (Endsley et al., 2017; Stapleton et al., 2002) in ways that are not be directly sensed.

Other dimensions of the schema share the physical-virtual-abstract bounds including the setting within which the experience takes place, the form of feedback participants receive, the nature of the objects that participants interact with, and the concepts presented.

LOCATION (SETTING) OF EXPERIENCE

The location dimension refers specifically to the representation of place. Location for representing the setting is an important element of location-based augmented reality experiences, being explicit in many definitions for augmented reality (Lin & Chen, 2015, Pavlik & Bridges, 2013). The term 'location' variously relates to sensitivity to the participant's location (Avouris & Yiannoutsou, 2012; Chen et al., 2013), to integrating the location with the experience (Deterding et al., 2011; Endsley et al., 2017; Richardson, 2016), and to utilizing the context of a specific location (Chatzidimitris et al., 2016; Schneider et al., 2017). This dimension explicitly focuses on experiences that are "deeply locative" (Rouse et al., 2015) and designed to exploit the context and nature of a specific location(s) as opposed to those intended for use regardless of the situation (K. Lee, 2012; Rouse et al., 2015) which use generic AR location-aware technologies.

Similar to the nature of reality, a blend of the factors abstract, physical, and virtual is required to define the setting, as shown in Figure 2. ***Physical*** refers to when an application is set in the real-world location that the participant is visiting and utilizes this physical environment. ***Virtual*** settings are provided as computer-generated synthetic elements that immerse the participant in the place without needing to be physically present. For example, a 360-degree projected space provides a virtual presentation accurately representing key properties of the location despite the intangible format. Opposing a concrete experience are those with an ***abstract*** link to the location employing imaginative or reinterpreted representations, or those that are not sensed directly. For example, an abstract location could involve inferring a first-person perspective from a third-person table-top view. A designer may choose to blend these dimensions but is also able to focus on just one and enrich the experience through design choices related to the other dimensions of an AR experience design.

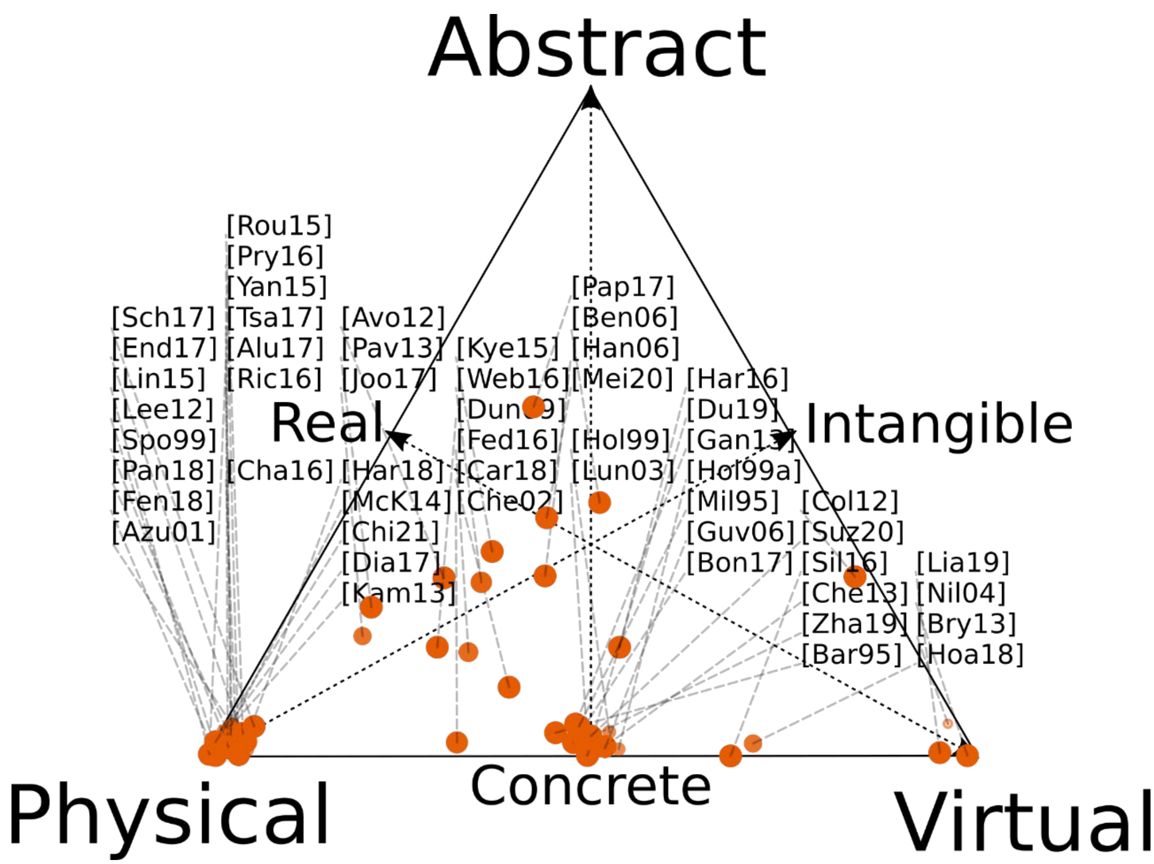

Figure 2. Defining location

Typical AR applications maintain a connection to the physical world to register it to the view observed through a camera (Endsley et al., 2017; Weber, 2016) although locations can be incorporated in many other ways. Locations can be distinguished into categories such as indoor and outdoor (R. T. Azuma, 1997; R. Azuma et al., 2001; Hollerer, Feiner, Terauchi, et al., 1999; Schneider et al., 2017), real or virtual (Avouris & Yiannoutsou, 2012; Chatzidimitris et al., 2016; Milgram et al., 1995), or to note the use of public space (Deterding et al., 2011) or geographic locale (Pavlik & Bridges, 2013), often because these affect choice of technologies to both track the participant and to capture the scene (R. Azuma et al., 2001).

Early interpretations of augmented reality (Barfield & Rosenberg, 1995) suggest that the location is either experienced directly in its physical form or provided virtually through a head-mounted display that is computer-generated or reconstructed from data captured from a real location (Hollerer, Feiner, & Pavlik, 1999; Du et al., 2019). The physical location may be the focus of the experience (Richardson, 2016, Schneider et al., 2017); for example, where a specific city is the setting of an AR experience played out at defined locations, or workplace training (Chiam et al., 2021). Alternatively, the location can just be a canvas representing context for overlaid content providing information, media, or virtual structures and objects (Guven, 2006; Hollerer, Feiner, & Pavlik, 1999; Spohrer, 1999). Information annotated onto the entire visible landscape identifies landmarks and mountains (Fedorov et al., 2016). AR games introduce fictional settings (Benford et al., 2006) distinguishing virtual representations of actual locations from more abstract settings for fictional or unconventional locations, such as regions represented at a microscopic scale (Cole et al., 2012). A role-playing experience in a medieval city (Papathanasiou-Zuhrt et al., 2017) exploits the physical location and enhances it with imaginative elements including a location-linked storytelling device. The concept of place attachment relates to the perception of a location as an attractive destination (Oleksy & Wnuk, 2017). Place attachment results in return visits to sites, or positive goodwill as required in commercial tourism activities (Papathanasiou-Zuhrt et al., 2017; Xu et al., 2016) by using the AR experience to encourage participants to bond with the location.

Experiences that do not depend on specific physical locations (Bonfert et al., 2017; Chatzidimitris et al., 2016), such as Pokémon Go (Aluri, 2017), can incorporate site context when the locations themselves adapt to include references to the AR experience (Aluri, 2017) by incorporating the application into travel guides. Such weakly locative applications are driven by activities linked to a map (Kamarainen et al., 2013; McKenzie et al., 2014; Weber, 2016) which are triggered by visiting those coordinates but otherwise do not rely on that specific location directly. Procedural generation can manufacture virtual settings that conform to the physical location (Cheng et al., 2019). Activities to encourage exercise can use physical augmentation of the setting such as RFID readers at key locations to register progress (Harris, 2018). A game of mystery set on city streets (Benford et al., 2006) uses part of the physical setting enhanced with a fictional overlay including actors and clues related to the setting. Technology-enhanced theatrical performances (Carlson et al., 2018) take place in a physical gallery with the setting enhanced with virtual elements.

Physical location plays a key role in AR experiences for museums (Fenu & Pittarello, 2018; Lin & Chen, 2015; Pang et al., 2018; Tsai et al., 2017), where the augmentation is information applied to individual objects in the room. Alternating reality (Hoang & Cox, 2018) switches between the physical location and a virtual location by alternating between viewing directly, and through a head-mounted display. Alternating is used in other tourism and educational applications (Joo-Nagata et al., 2017; Kysela & Storkova, 2015) where a tour of a physical city is enhanced with virtual content (e.g., architectural models) with some fictional, historical, or abstract representations using map-based representation or information overlays. Virtual overlays in the setting can make use of modalities such as sound (Chatzidimitris et al., 2016), map-based representations (Chen et al., 2013; Dunleavy et al., 2009; Lundgren & Bjork, 2003), or head-up information overlays (Ganapathy, 2013; Pryss et al., 2016) to present aspects of the setting that may not be directly visible. Participants may share the space across different forms of the location: physically present, as 360° images captured from atypical viewpoints (Zhao & Klippelt, 2019), as maps, or exploiting proximity rather than absolute location (Lundgren & Bjork, 2003). Pervasive computing applications provide a form of computational augmentation to the physical environment (Diaconu et al., 2018).

The location itself may be completely virtual and experienced through a head-mounted display, through a small "window" provided by a mobile screen (Cheok et al., 2002), or through a projection onto a tabletop surface (Brederode et al., 2005; Nilsen et al., 2004). Locations presented virtually through a head-mounted display may nevertheless incorporate structural and tactile elements of the physical setting (Silva et al., 2016), or recreate familiar environments such as a virtual classroom (Suzuki et al., 2020). The virtual location may represent the actual physical location, such as when allowing a performer to monitor their own performance (Yan et al., 2015).

AR also supports locations that could never be visited in person. Locations at different scales (e.g., microscopic (Cole et al., 2012)) can be interpreted virtually or physically in ways that communicate relevant properties of the setting. Historical views are provided by augmenting a contemporary location with representations of the past (Pavlik & Bridges, 2013), or cultural content can be reimagined in game worlds (Meier et al., 2020). Annotation systems allow the added content to be experienced at the physical location, but also in virtual environments or other representations of the location (e.g., a web page) (Hansen, 2012).

FEEDBACK

Interaction in mixed reality sometimes fixates on the mechanisms for managing participant gestures and movements (Collins et al., 2017) although such low-level actions can be progressively abstracted into more complex sets of behaviours (de Ribaupierre et al., 2014) that are both efficient and expressive (Dey et al., 2018). In AR, the interactivity should consider the balance between feedback, objects, and concepts to facilitate a space of activity. Figure 3 defines the relevant categories to define feedback presented in any AR application.

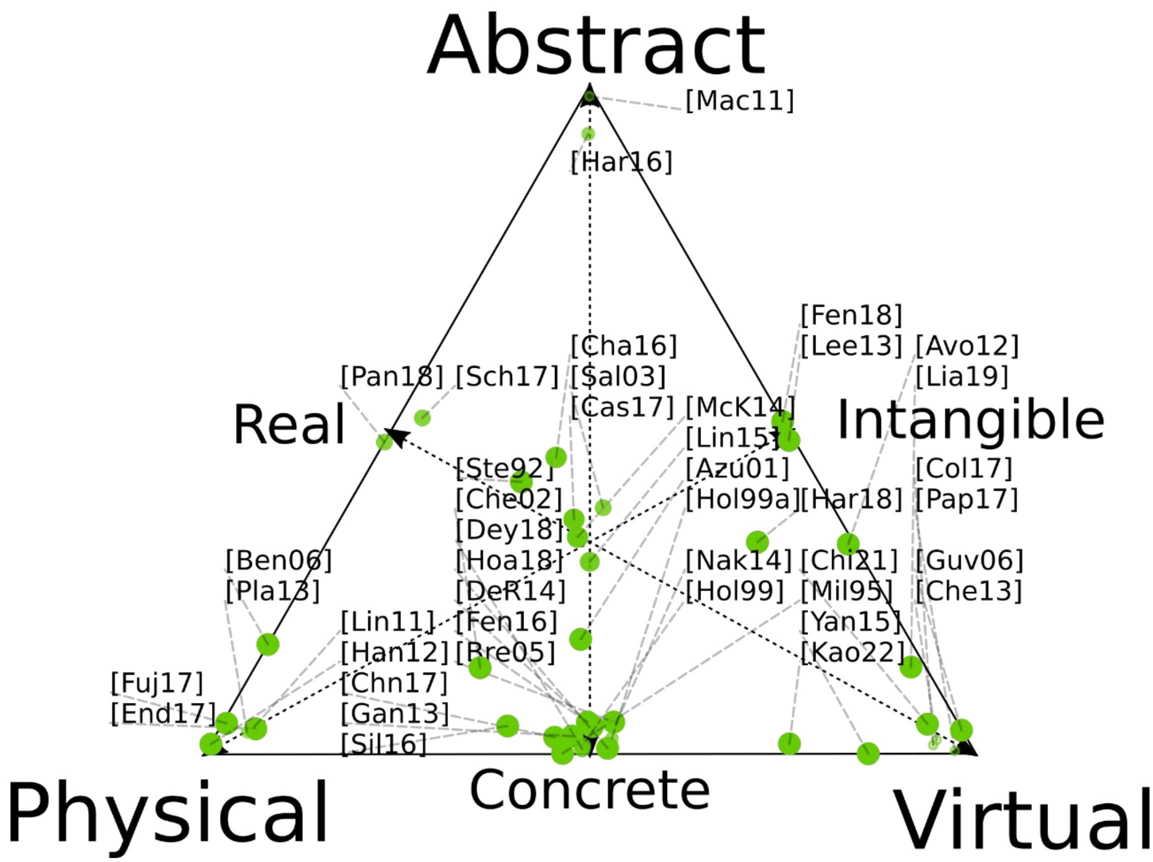

Figure 3. Defining feedback

Feedback is classified as ***physical***, ***virtual,*** and ***abstract*** based on the form of feedback. Physical feedback involves physical interactions through real-world elements. Virtual feedback is mediated through technology such as a pop-up tour guide in a museum that responds to queries (Lin & Chen, 2015). Feedback in the physical world is a response to moving around the space of action, and in the virtual world occurs through actions of interface elements or viewing the space of action through an AR view. Abstract feedback is participant mediated such as a trigger for imagination or an emotional response (Salen & Zimmerman, 2004). It is indirect and requires further interpretation such as inferring the behaviour of a ghost based on particular noises or of changes in personal status based on points scored.

The feedback dimension covers the actions of the participant, and the stimuli presented to the participant in response to actions. Feedback provides an engaging participant experience and a way for participants to evaluate the consequences of their actions (Fernandez-Cervantes et al., 2016; Weber, 2016), particularly in mixed reality settings where traditional cues do not apply. Interaction involves a feedback loop where the participant provides input to the experience, and the output from the experience is reciprocally presented to the participant (Salen & Zimmerman, 2004; Steuer, 1992). The part of the feedback loop representing the actions provided by the participant can be achieved by using physical objects directly (Ch'ng et al., 2017), or re-imagined as particular tools (R. Azuma et al., 2001; Cheok et al., 2002) by manipulating their appearance with a visual overlay. The participant's body can be regarded as the physical source of actions (Hansen, 2012); for example, re-imagined as an asteroid participating in a planetary simulation (Lindgren & Moshell, 2011). Actions achieved without direct physical action include input in the form of speech, as input via a touch screen (Hollerer, Feiner, & Pavlik, 1999; Lin & Chen, 2015), or by clicking on points of interest using a trackball (Guven, 2006). Mappings (Steuer, 1992) translate the information being exchanged between participant and experience. The input and output directions of information flow can use different mechanisms. For example, the participant may act on physical objects but see the response presented in the virtual overlay (Brederode et al., 2005).

Typical augmented reality applications concentrate on the presentation aspect mixing the actual physical setting with virtual content that may be presented visually or using other modalities, e.g., audio (Ganapathy, 2013), smell (Silva et al., 2016), or haptic (R. T. Azuma, 1997; Fujinawa et al., 2017). The physical and virtual feedback elements can complement one another in the ways they communicate concepts (Hoang & Cox, 2018), mixing the physical spatial concepts with virtual reimagining (Milgram et al., 1995). In a role-playing setting, physical actors provide feedback through performance, although this may need to be interpreted within the context of the story (Benford et al., 2006). Robotic museum guides provide the opportunity for physical responses as well as audio feedback (Pang et al., 2018). The actions of other co-located participants are also a form of direct physical feedback (Cheok et al., 2002) while an avatar representing the participant provides virtual feedback of his/her own physical movement during exercise training (Fernandez-Cervantes et al., 2016; Yan et al., 2015). Body-based forms of feedback enhance participant embodiment due to the physical connection (Hansen, 2012).

While the physical environment of an augmented reality experience suggests the use of tangible and physics-based metaphors (Endsley et al., 2017) to provide feedback, the information presented to the participant need not be in a concrete nor a visual form. New forms of feedback and interaction bridge between the physical and virtual world, and allow imaginary elements to become tangible through experience (Ganapathy, 2013). Ghosts in an augmented Pacman game can be implied using sound effects (Chatzidimitris et al., 2016), rewards provided as status on a leader-board (Macvean, 2011), narrative, and clues on an iBook screen (Papathanasiou-Zuhrt et al., 2017) or by an invisible narrator (Castaneda et al., 2018), while the effect of a detonating mine might be presented as a change in score (Cheok et al., 2002).

OBJECTS

The objects dimension specifies the nature of the discrete elements with which the participant interacts. Objects in an AR experience include both virtual and physical items and may represent real objects, parts of an environment, or abstract elements in the experience (Avouris & Yiannoutsou, 2012; R. Azuma et al., 2001; Benford et al., 2006; Ch'ng et al., 2017). Examples include the virtual elements that appear on surfaces captured from the real world (Roo & Hachet, 2017) whereas physical objects can become tangible interactive elements by projecting content onto them (R. Azuma et al., 2001; Brederode et al., 2005; Van Krevelen & Poelman, 2010).

Figure 4 demonstrates the dimension for objects, again allowing the designer to specify the mix of physical, virtual, and abstract elements. Objects in AR may exist in a ***physical*** sense, as part of the existing environment, or placed artificially. ***Virtual*** objects are representations of objects presented through computer-generated means to produce the virtual overlay. Virtual objects appear in 3D locked in position relative to a physical location (Fenu & Pittarello, 2018), although sometimes the overlay is a control for a physical object or information content covering a particular concept (Tsai et al., 2017). The benefit of working with virtual objects is that the need for a common physical location becomes optional. Objects may also be ***abstract***, providing a representation that is not immediately discernible or meaningful for the participant, such as the presentation of an 'aura' (Richardson, 2016). Abstract objects may be part of the narrative, such as points scored, treasure collected during the experience (McKenzie et al., 2014), or indirect representations of objects using sound cues (Chatzidimitris et al., 2016) to represent ghosts and cookies in an audio augmented game of Pacman. A designer can blend any selection of objects in their application and should consciously decide on which are most appropriate to their requirements.

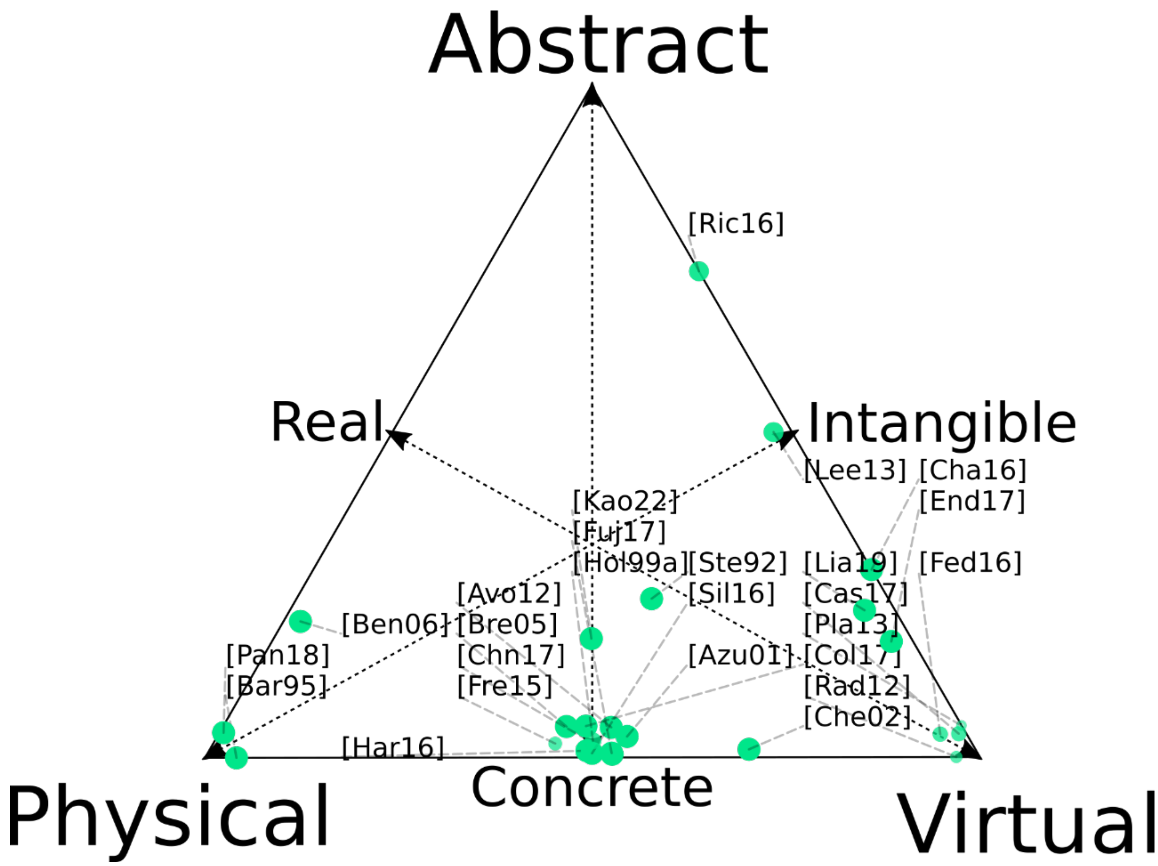

Figure 4. Defining objects

Objects in an AR experience can be defined in a physical sense, from real-world books to furniture. The interplay between physical objects (desk lamp and notebook) and interactivity in a desk simulation shows how these objects transition from real to augmented during the simulation (Collins et al., 2017). Moveable physical objects in an AR scene can be tangible control elements for manipulating the virtual overlay (Brederode et al., 2005) such as physical puzzle cards that present virtually as logical functions to embody programming abstraction (Kao & Ruan, 2022).

Virtual objects can take physical objects and remap them to the virtual overlay to change their appearance (Cheng et al., 2019; Silva et al., 2016). This can be used, for example, to substitute physical obstacles with plausible virtual objects that need to be avoided. Such objects exist on the reality-virtuality continuum from real to virtual (Milgram et al., 1995). The interplay between physical and virtual objects enables participants to better interact with the visual information, providing a tangible interface to support participant interaction with complex information (R. Azuma et al., 2001). Virtual AR objects are presented differently than in a non-AR medium: verbal descriptions become visual, static images become animated, 2D representations become 3D objects, and non-interactive content becomes interactive (Radu, 2012). Virtual objects and elements in an AR experience add customizable complexity but require a degree of persistence (Nilsen et al., 2004) to ensure they represent a form of computer-mediated communication that is understandable by the participant. A mixed-reality art-science collaboration focused on an artificial life ecosystem (Ch'ng et al., 2017) combines virtual and real objects, with computational agents employed to enable interaction between participants and objects.

Virtual objects (and potentially physical) may not have a direct representation in the participant's known understanding of the real world. AR objects afford the opportunity for novel, imaginative and surprising interaction to occur (K. Lee, 2012; Radu, 2012; Richardson, 2016). For example, a serious game in medicine has tasks spanning several levels of abstraction, from kinematic and dynamic aspects to domain knowledge training (de Ribaupierre et al., 2014). Virtual pets provide a relationship between objects and a player's actions (J. J. Lee et al., 2013).

CONCEPTS EXPLORED

The concepts explored dimension describes the nature of the information that the participant is engaging with through the context of the experience. AR experiences cover a wide range of contexts, being used for purposes such as visualization, supporting assembly and maintenance, shopping assistants, games and entertainment, historical recreation, tourism, and training in areas such as surgery (R. T. Azuma, 1997; R. Azuma et al., 2001; Deyet et al., 2018; Ganapathy, 2013). These involve different levels of abstraction ranging from manufacture and repair of existing physical equipment (R. T. Azuma, 1997; Barfield et al., 1995), to providing a virtual overlay of ultrasound images (Barfield & Rosenberg, 1995) or forensic evidence (Avouris & Yiannoutsou, 2012), or developing knowledge of concepts such trade and religion (Avouris & Yiannoutsou, 2012).

Figure 5 is used to classify the concepts explored. ***Physical*** concepts are those that are practical and hands-on, typically with a focus on spatial structure and relationships, for example, a site tour or a frog dissection. ***Virtual*** concepts convey ideas that cannot practically be represented physically, overlaying information about physical objects, such as historical views that no longer exist, showing a flow of air around objects or data such as concentrations of chemicals at various points in the location. ***Abstract*** concepts are those that cannot be presented spatially such as social relationships, emotion, or abstract mathematical ideas, and may include elements of deduction or reasoning. Consequently, real concepts are physically verifiable, but not always visible or directly representable.

Physical concepts covered include equipment repair, but also to developing motor skills (Dey et al., 2018; McKenzie et al., 2014), self-assessing dance performance (Yan et al., 2015), and improving physical fitness (Cutter et al., 2014; Harris, 2018) allowing clinical assessment (Ellmers et al., 2017). Such experiences can adapt to the needs of the participant, both in difficulty but also by considering physical ability and age (Planinc et al., 2013). Overlays provide ways of presenting content that is not physically present. This ranges from retail spaces where virtual stock can be shown on the shelves (Brynjolfsson et al., 2013) to remote collaborations (Dey et al., 2018).

Higher levels of abstraction are achieved through applications based on puzzles and mysteries that tolerate levels of ambiguity (Benford et al., 2006; Dunleavy et al., 2009). Games are another way of presenting abstraction, through rules that engage with abstract concepts such as ensuring social interaction between children of differing capabilities (Brederode et al., 2005) or modifying attitudes and behaviour (Cole et al., 2012; Cutter et al., 2014; Harris, 2018; K. Lee, 2012). Exploring and problem-solving in an AR experience provide opportunities to practice and develop language skills (Richardson, 2016), or learn programming abstractions (Kao & Ruan, 2022). Simulations work across multiple levels of abstraction and develop problem-solving skills (de Ribaupierre et al., 2014) and convey the complexities of ecosystems (Schneider et al., 2017). Museum and tourism experiences present media to develop both better awareness of their content but also to develop an emotional attachment to the topic, culture or place (Fenu & Pittarello, 2018; Hoang & Cox, 2018; Joo-Nagata et al., 2017; Kysela & Storkova, 2015; Lin & Chen, 2015; Pang et al., 2018; Papathanasiou-Zuhrt et al., 2017; Tsai et al., 2017; Weber, 2016; Zamora-Musa et al., 2018).

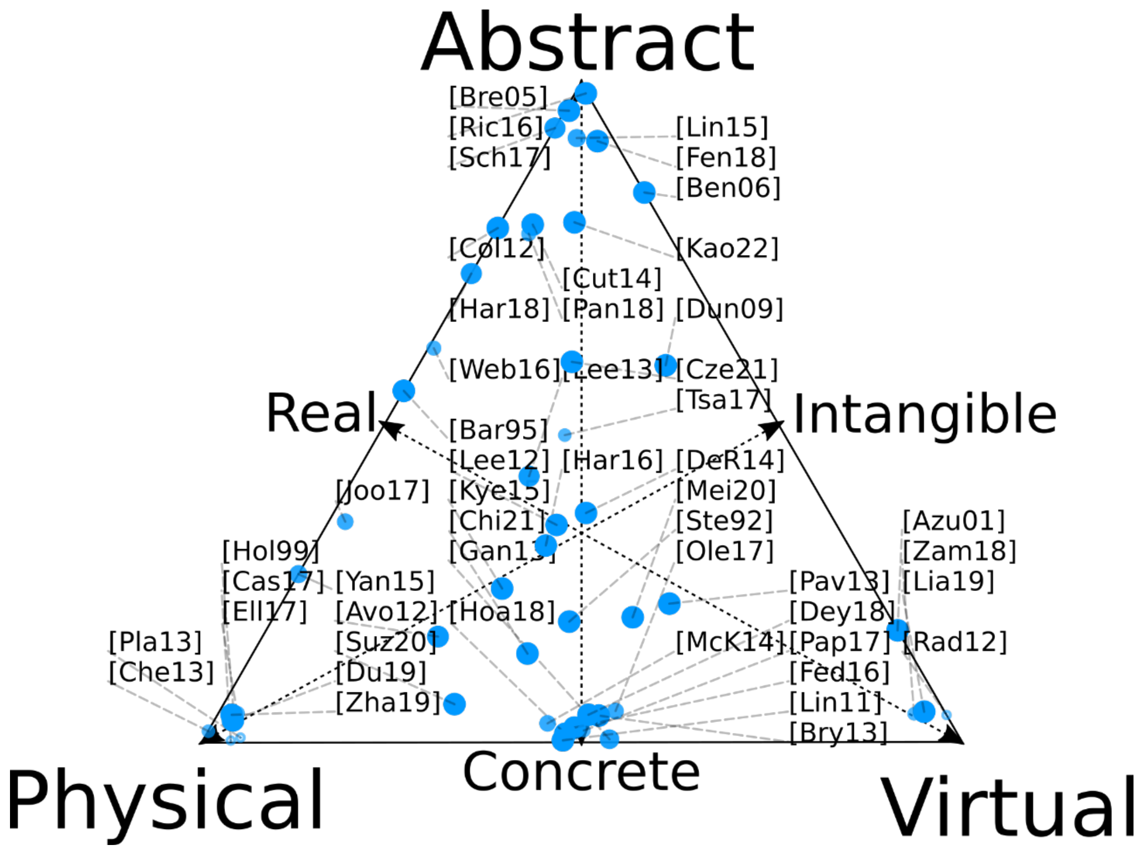

Figure 5. Defining concepts

Teaching a concept is particularly relevant to education and training. Educational experiences span the range, teaching variously physically oriented concepts such as transportation choice or operating equipment (Radu, 2012) or virtually overlaid concepts such as the greenhouse effect. Teaching abstract concepts is common, involving developing empathy and social norms (J. J. Lee et al., 2013), learning to use AR in lesson design (Czerkawski & Berti, 2021) or learning properties of the physical environment through virtual scenarios while dealing with abstraction in the form of social interactions (Chiam et al., 2021). Concepts can be explored using problem-solving, discovery, experimentation, or through mini-emergent elements (Richardson, 2016; Xu et al., 2016). AR applications teach through active experiences, support collective learning, adapt to individual needs, and allow the construction of knowledge (Dunleavy et al., 2009). Participant-created content supports knowledge sharing between participants (K. Lee, 2012).

Participant Presence

When designing the participant experience considerations of experience and presence guide the design of the activity structure for the participant (International Society for Presence Research, 2000). Participant presence considers how participants are engaged with the experience and with one another. Human perception of an AR experience can be considered in terms of presence, which is a prominent component of our conscious human experience (Carlson et al., 2018). AR interactive experiences provide varying degrees of physical presence, providing physical proximity for participant interaction, as well as virtual or telepresence which is largely technology-mediated.

Figure 6 describes the three elements that define participant presence. ***Physical presence*** occurs when the interaction is between participants in physical proximity, with ***telepresence*** occurring when it is technology-mediated usually because the participants are not co-located. ***Copresence*** occurs when engagement is primarily with the experience, rather than with other participants who may be at the same location.

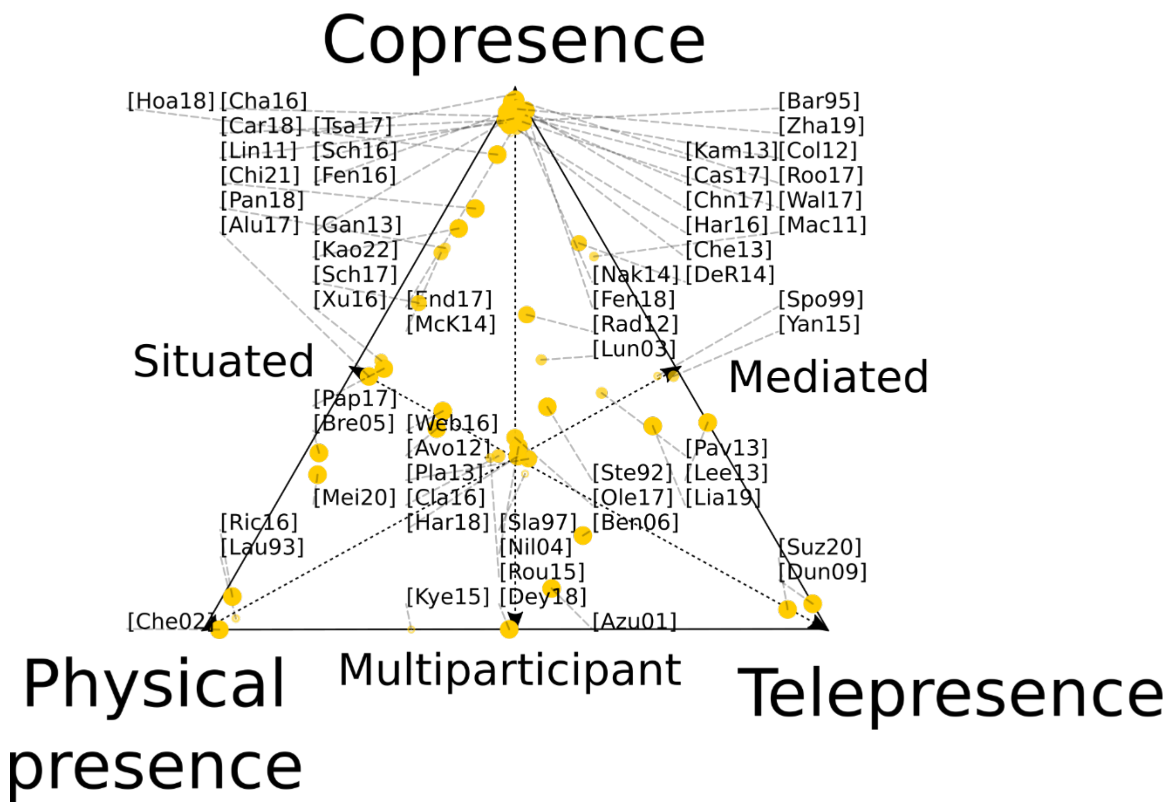

Figure 6. Designing participant presence

The physical connection provides human-mediated presence allowing participants to connect either to the environment or to other participants (Aluri, 2017; Cheok et al., 2002; Nilsen et al., 2004; Papathanasiou-Zuhrt et al., 2017; Richardson, 2016; Slater & Wilbur, 1997). Engaging in the physical world also provides the opportunity for meaningful interaction between participants and the environment, and also between participants (Harris, 2018). The physical interaction between participants in an AR experience is of considerable value as it ensures the human connection is mediated and connected to the real world (Cheok et al., 2002). An AR experience may use direct communication in the physical environment even when access to the virtual overlay is shared among the participants (Schneider et al., 2017).

Participant presence may be provided through virtual or telepresence mechanisms, providing a technology-mediated experience for the participants (R. Azuma et al., 2001; Brederode et al., 2005; Dey et al., 2018; Dunleavy et al., 2009), such as collaborating through remote control of equipment (Suzuki et al., 2020). The telepresence mechanisms can virtually monitor the AR experience, and provide a variety of objects and feedback to guide the participant's experience to provide engagement. Engaging with others is usually indicated visually, but can also be achieved through audio cues (Cheok et al., 2002) which supports awareness of others even when they are outside the field of view. A collaborative experience can involve the interaction between physical and telepresence (R. Azuma et al., 2001). Social contact while playing Pokémon Go predicts active place attachment (Oleksy & Wnuk, 2017).

AR also has the potential to allow participants to co-inhabit the same physical space with other participants, providing opportunities for technology-mediated collaboration and copresence (Dunleavy et al., 2009; Harris, 2018; Kysela & Storkova, 2015), such as a shared story space (Pavlik & Bridges, 2013). Participant presence considers what kind of relationships the participant forms during the experience and describes the way the experience connects the participant to and across the physical or telepresence domains (Aluri, 2017). Recordings of students working through electronic resources can be triggered at appropriate times, providing technology-mediated but asynchronous collaboration through the student's virtual avatar representations (Liao et al., 2019). Copresence in mixed reality experiences can generate face-to-face social interaction through the use of common public spaces (Clark & Clark, 2016). It may see participants engage in a multi-participant experience connected via technology, as teams with only a single device per team, or completed completely solo, such as the cultural heritage experience (Joo-Nagata et al., 2017). Team cohesion is reportedly improved when working with AR content (Radu, 2012). Progress can also be monitored virtually in these experiences (Benford et al., 2006), impacting both the social and collaborative experience (K. Lee, 2012; Macvean, 2011). Games have the potential to encourage and support social interaction amongst players providing participant presence as they can bring together like-minded individuals visiting a particular location to participate in a common and mediated activity (Aluri, 2017; Brederode et al., 2005; Nilsen et al., 2004; Papathanasiou-Zuhrt et al., 2017; Xu et al., 2016). Assassination games rely on both physical (co-location) and virtual (game play mechanics) to provide participant presence (Avouris & Yiannoutsou, 2012).

Interactive Agency and Style

AR experiences can just present virtual, physical, and abstract content but richer engaging experiences result from including additional structure (R. Azuma et al., 2001). Such structures include narrative, ludic, and roleplaying elements (Avouris & Yiannoutsou, 2012; Cheok et al., 2002; Salen & Zimmerman, 2004).

As shown in Figure 7, the corners of the triangle mark the extent to which the application incorporates ***performance*** aspects (Rouse et al., 2015), ***narrative*** elements, and ***ludic*** structure (Schneider et al., 2017). Performance includes active and interactive elements that provide a sense of agency for the participant (such as role-playing) (Fernandez-Vara, 2009; Rouse et al., 2015). The narrative represents the degree of the structured story present in the experience (Walk et al., 2017) which participants can experience but have limited effect on the outcome. Ludic elements impose particular rules defining an explicit relationship between actions and outcomes but allow participants to explore the space of possibilities within this structure (Lundgren & Bjork, 2003; Stapleton et al., 2002; Walk et al., 2017).

The popularity of ludic elements (Aluri, 2017; Avouris & Yiannoutsou, 2012; Brederode et al., 2005; Chatzidimitris et al., 2016; Nilsen et al., 2004; Silva et al., 2016) is attributed variously to the opportunity to engage the participant as an actor through multiple senses (Steuer, 1992), to opportunities to shape behaviour (Cole et al., 2012), provide motivation (Deterding et al., 2011), disguise dull training activities, (Schoneveld et al., 2016) and to support task-based collaboration (Cheok et al., 2002). Gaming experiences market tourism locations even prior to visiting them (Xu et al., 2016). Location-based games facilitate attachment to that place (Oleksy & Wnuk, 2017; Weber, 2016). The game itself pervades across multiple realities: using physical pieces, in virtual worlds on a computer, or mixtures of these through projections (Lundgren & Bjork, 2003).

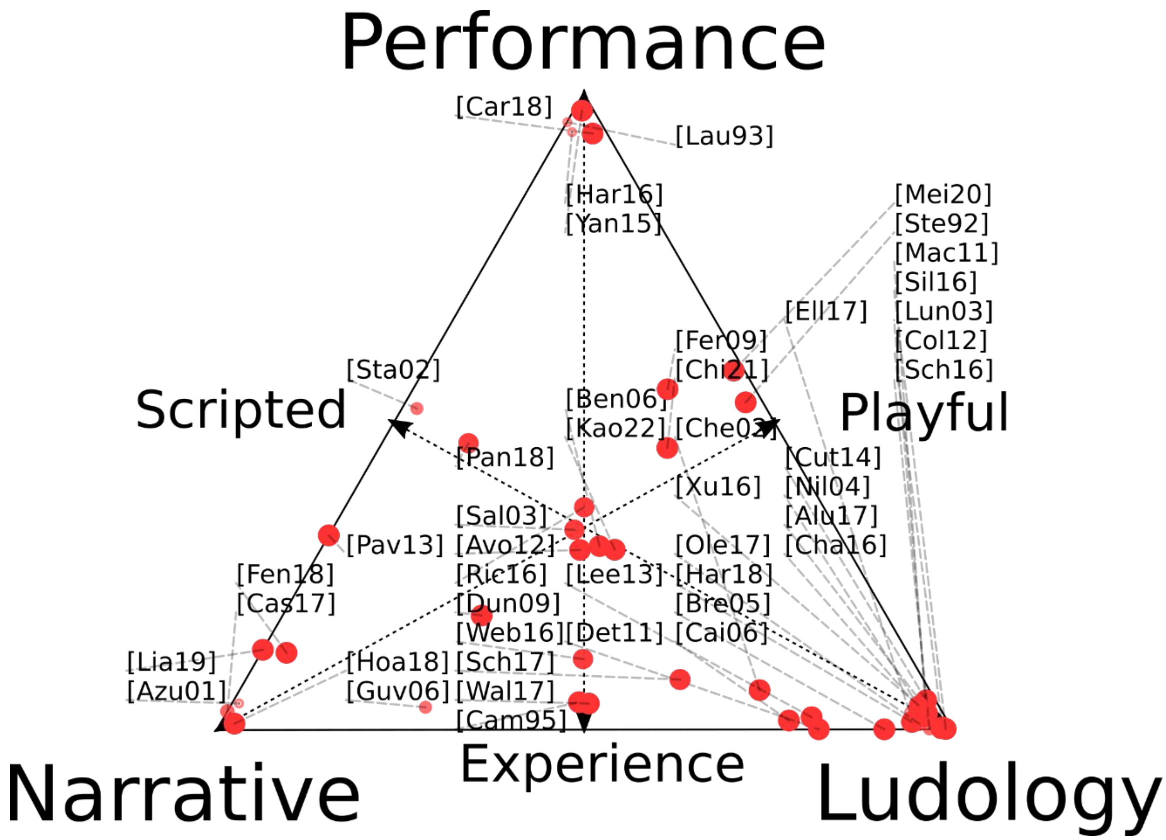

Figure 7. Designing the interactive agency and style

Story elements, either embedded or emergent, are fundamental in game design frameworks (Walk et al., 2017). Game objectives are often expressed in the context of a story (Brederode et al., 2005, Dunleavy et al., 2009) but narrative elements can also be distinct from the game. Stories have a more rigorous schedule and are less frivolous in nature (Cameron, 1995), and are thus supportive of educational goals (Schneider et al., 2017). The interaction may be limited to visiting each location as the story unfolds (Fenu & Pittarello, 2018; Guven, 2006) under the guidance of a narrator (Castaneda et al., 2018) or can provide opportunities to control and direct the story (Pavlik & Bridges, 2013; Stapleton et al., 2002). The narrative is driven by participant actions as they collaboratively solve puzzles and unravel the story (Dunleavy et al., 2009; K. Lee, 2012; Nakevska et al., 2014). The narrative may be presented in a linear fashion, or as a series of threads (Rouse et al., 2015) integrated with the aspects of the performance. These can leave a mark on the setting by projecting images onto buildings and updating these images to respond to the emerging experience. For example, an overall narrative weaves a common thread through AR activities at multiple monument locations in a gamified tourism experience in the city of Rhodes (Papathanasiou-Zuhrt et al., 2017). Narrative constructs the bridge between virtual and real in an exhibition highlighting architectural elements of Walter and Marion Griffin's buildings (Hoang & Cox, 2018).

Game playing in a social setting (Cheok et al., 2002) also has performance aspects enhanced through the explicit inclusion of actors (Benford et al., 2006). Observers may be observing indirectly, immersed as part of the scene, or can even influence the outcome by their presence. This adds risk through drawing uninitiated bystanders into the virtual setting balanced by the opportunity to challenge expectations about acceptable behaviour. Substantial but invisible "stage" management protects players and ensures progression (Benford et al., 2006). Dramatic elements may be regarded as frivolous but are also relevant to serious activities (Laurel, 2013). Games and game engines can be used as an environment for learning through authoring content (Meier et al., 2020), in a process that combines performance with play. Robotic guides employ both storytelling and performance to entertain and educate (Pang et al., 2018). A physical rehabilitation exergame likewise combines game elements with performance by encouraging participants to act out previously recorded poses (Fernandez-Vara, 2009), and provides feedback with regard to accuracy. Participants may have specialist roles that have access to exclusive information to encourage social interaction (Dunleavy et al., 2009), combining acting out the assigned role with the game play associated with solving a puzzle.

DISCUSSION

The goal of this paper is to comprehensively define the design opportunities for AR experiences by developing a classification schema that systematically describes design choices. The application of the classification schema to a broad range of AR applications has been demonstrated in producing Figures 1-7 providing explicit choices for designers that are made across the seven dimensions.

Within the literature reviewed, the median number of dimensions per case study is 3 (mean 3.7) suggesting that existing design reporting focuses only on particular features, rather than providing the opportunity to consider design from a broader perspective. Ideation can be achieved by sampling coordinates across all triangles and devising design concepts that map to these coordinates. This process is applied to domains such as education, tourism, exhibitions, health, and entertainment that benefit from considering the many dimensions of an AR experience, to produce richer and better integrated AR application designs. Once an area has been chosen within each dimension, literature at nearby coordinates can be used as inspiration for specific design decisions. Figures 1 to 7 also yield interesting insights; for example, augmented reality experiences covering abstract concepts (Figure 5) are more common than might be anticipated for "reality" focused applications, while abstract objects (Figure 4) are an opportunity to be explored introducing imaginative or unusual content into an AR experience.

Using the classification scheme is not without its limitations. The schema is not intended to be prescriptive but is an agile tool to support AR experience design. Useful designs result from debating interpretations of schema descriptions and coordinates, which opens opportunities for innovation. The authors make no claims that any particular coordinates are superior designs to any others but do note that the centre of each triangle does offer the greatest mixture of the different classification criteria. Literature selection focused on diversity and thus the density of clusters shown is likely an artefact of this sampling process. However, empty regions do suggest opportunities for novel forms of AR experience. The schema focuses on design opportunities and can only help to identify exemplars when guiding implementation decisions around the choice of technologies or specific interaction strategies.

CONCLUSION

The goal of this paper is to present a classification schema and design rationale for AR. This uses seven dimensions that designers and researchers should use when making explicit choices about creating an AR experience. The dimensions provided represent the richness and diversity of AR applications and are derived by combining previous taxonomies with other design elements of innovative AR applications identified through the review of the literature.

This classification incorporates the descriptive abilities of its base taxonomies but is specifically created to support understanding requirements and developing a design for an AR application. The triangles, enhanced with references to existing applications, enable diverse teams to agree on design intent, explore other options, and consider alternate technical and implementation strategies. Most of the AR applications in the reviewed research focus on a subset of the categories identified, suggesting that other dimensions might not be considered during the design process and that this classification scheme serves to consistently report on all aspects of an AR experience. The breadth-first literature review ensures the resulting classification schema is multi-disciplinary, relevant, and representative, despite significant differences in focus across the literature identified.

Further extensions of this work would exploit the extensible nature of the schema to include categories representing design considerations resulting from advances in the field of mixed reality, or by including technology-focused elements required to support the implementation of these experiences.

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